Fermilab
An Introduction

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Fermi National Accelerator Laboratory

June 4, 2013

Summer Student Lecture Series

U.S. DEPARTMENT OF ENERGY

Fermilab

Outline

Let's talk about the Universe

Fermilab:

A Little Past, An active Present, An Outstanding Future

Particle physics on the Prairie

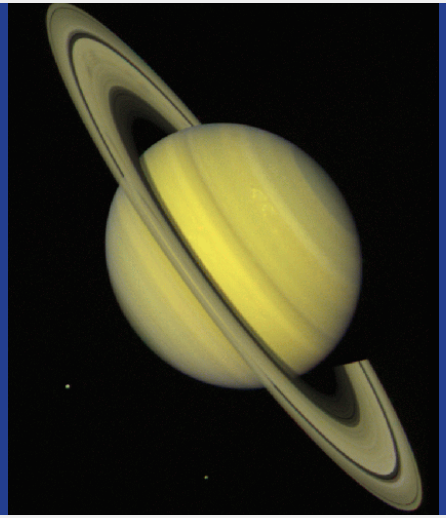
What you will hear this Summer

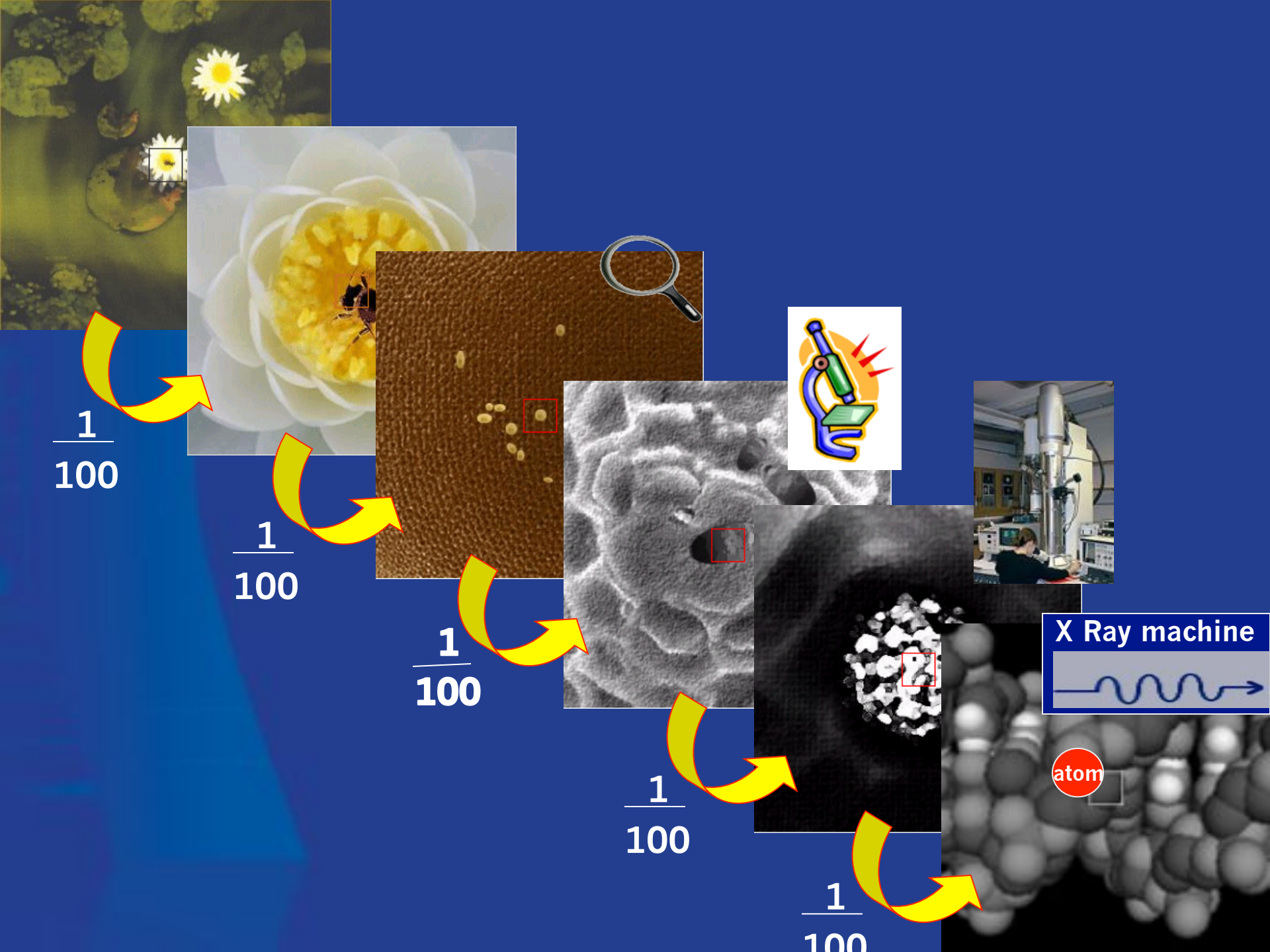
The Adventure

What is the Universe made of?
What are the smallest things we can study?



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100
1
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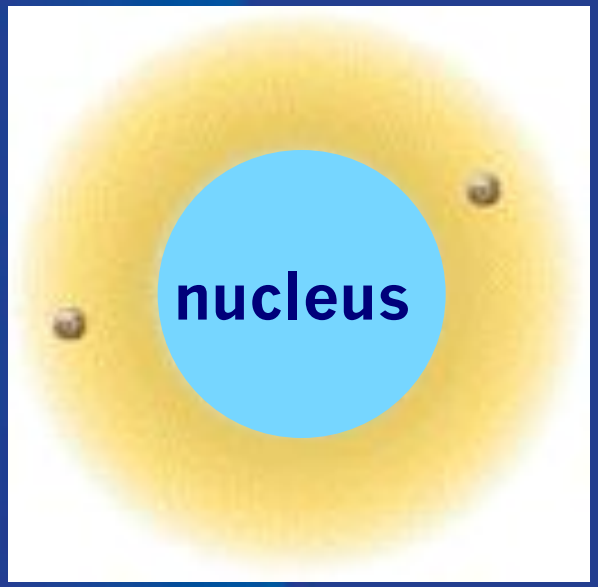
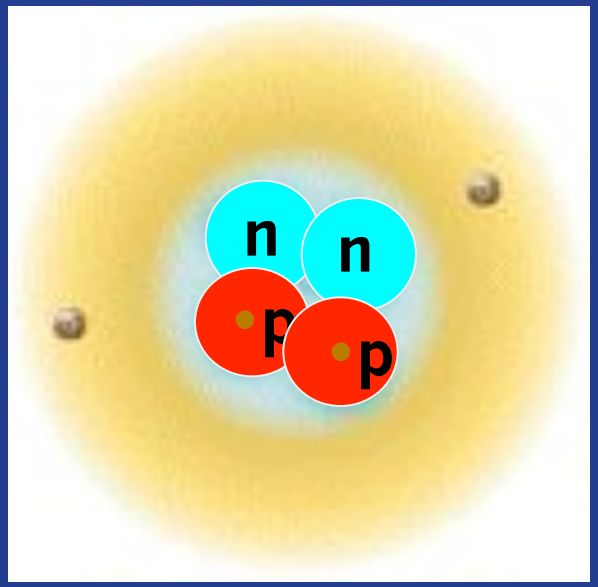
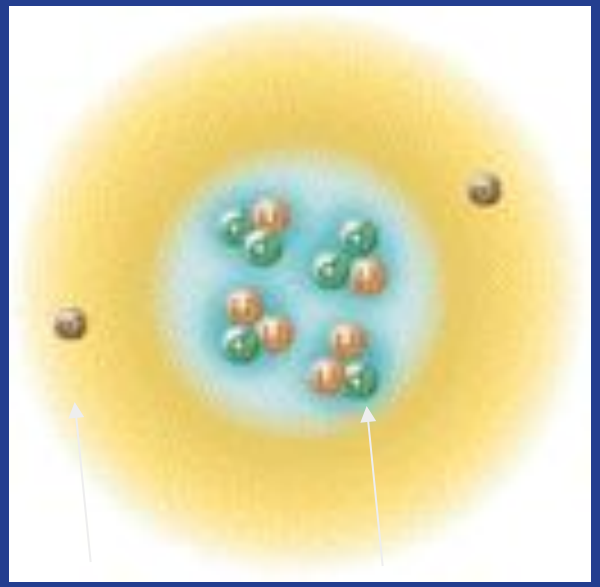
100
X Ray machine
atom

Everything that we can see is made of electrons, and smaller particles.





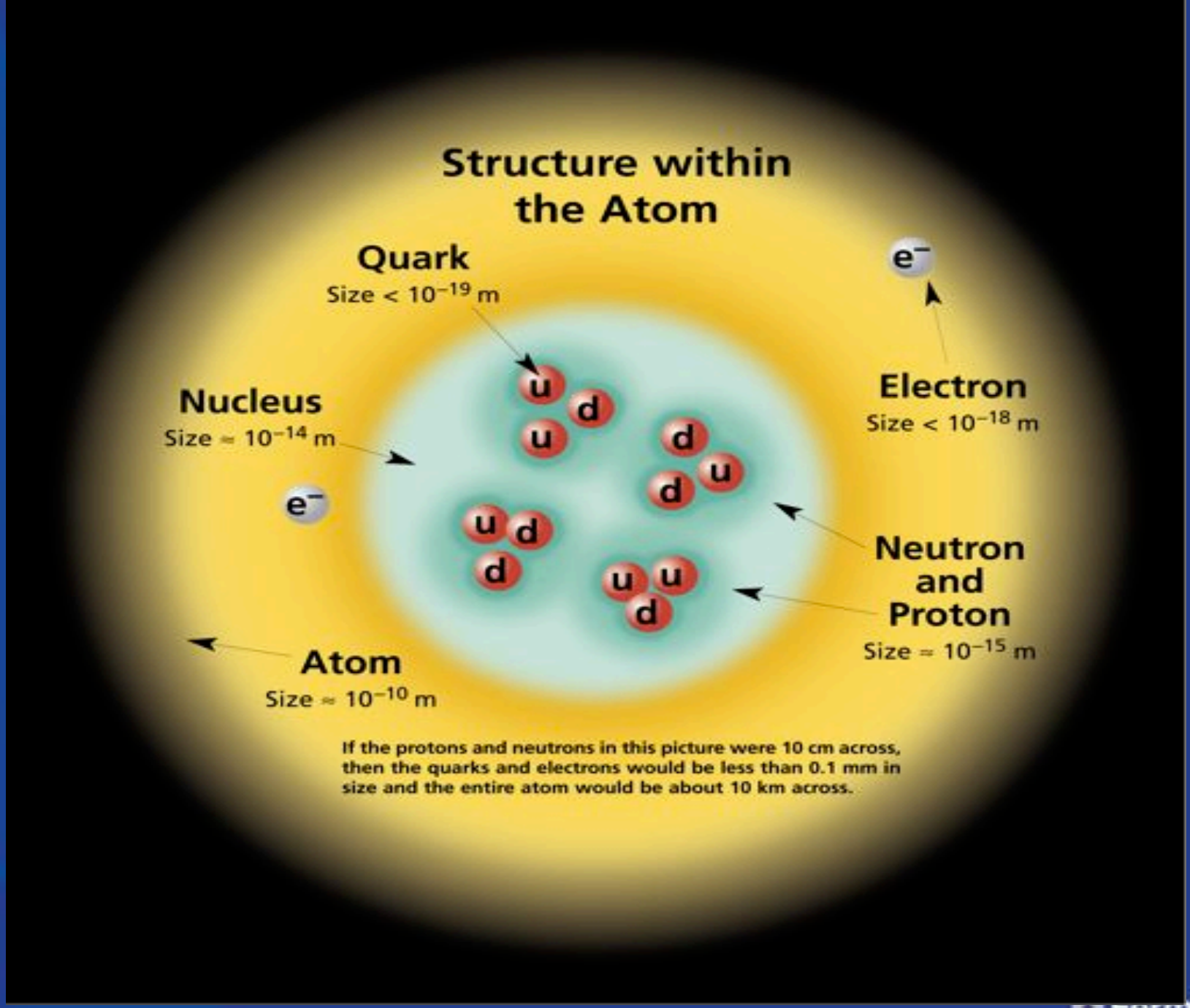


Electron Quark

0.00000000000000001 m

nano nano meter

higher beam particle energy = smaller size you can see


Structure within the Atom
Quark
Size < 10^{-19} m
e^-
Electron
Size < 10^{-18} m
Nucleus
Size ≈ 10^{-14} m
e^-
u
d
u
d
d
u
u
d
d
u
u
d
Neutron and Proton
Size ≈ 10^{-15} m
Atom
Size ≈ 10^{-10} m
If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

Fermilab:
A Great Past, An active Present, An Outstanding Future

Fermi National Accelerator Laboratory advances the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high energy physics and related disciplines.

The First Accelerators

Lawrence and Livingston began developing this 4.5-inch cyclotron in 1929-30.

Livingston (left) and Lawrence with the magnet of the 27-inch cyclotron, operating in 1932 at 3.6 MeV.

Courtesy: Adrienne Kolb, Fermilab

Fermilab

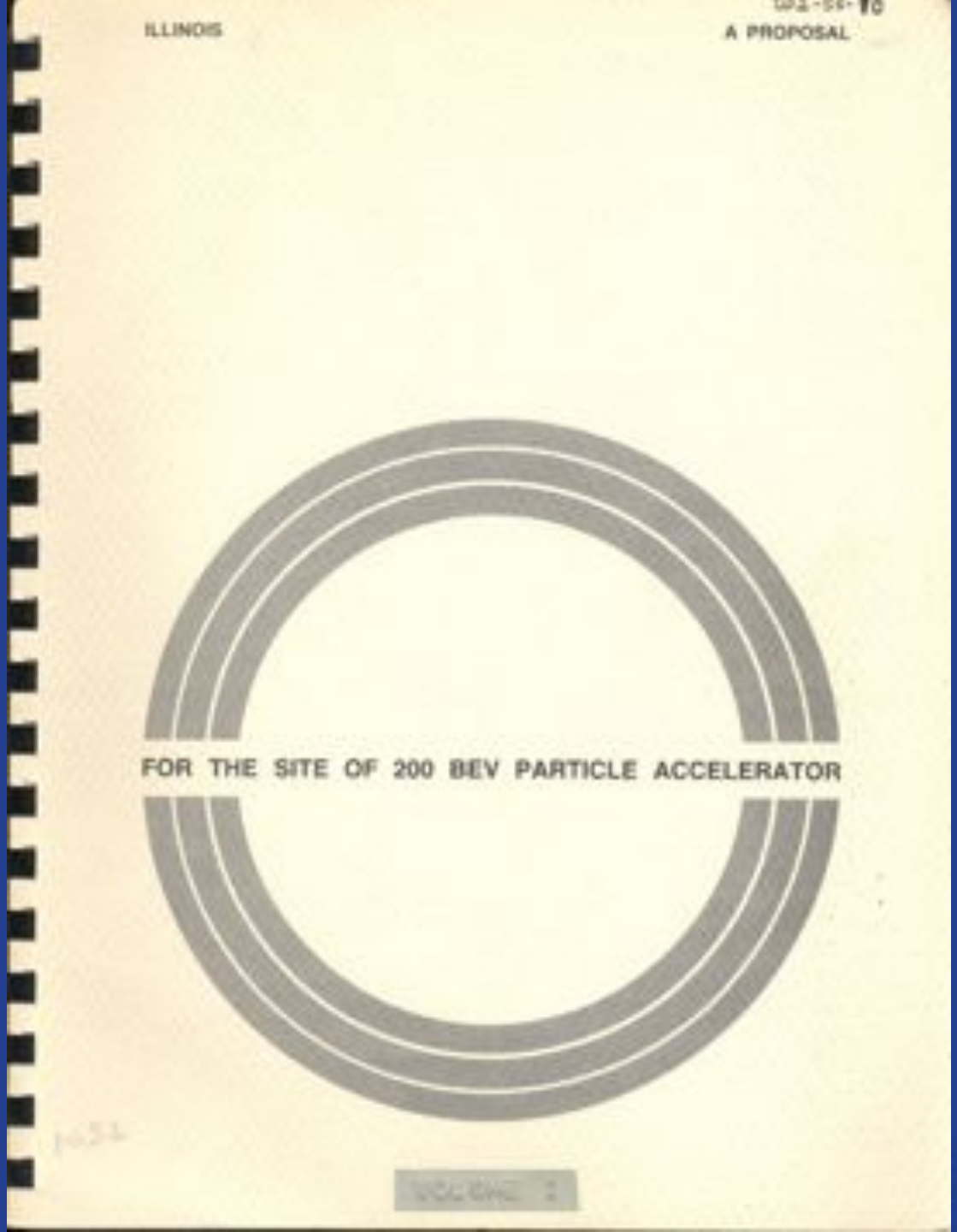
Physics Drivers

1940's	Basic Nuclear Structures Studies	Cyclotrons
	Nuclear Structure	
	-QED	
1950's-60's	Particle and Particle Properties	Synchrotrons
1960's-70's	Substructure	
	-QCD	
1980's-2000	Finishing the Standard Model	Lepton Colliders
		SSC, TeV
2000-----	Search for new particles	LHC, TeV
	Symmetries and New Matter Types	

Fermilab:

- A federally funded research facility part of the
  - **U.S. Department of Energy**
- that is managed and operated by Fermi Research Alliance, LLC.
- A vital part of the Kane and DuPage County communities and of the growing northeastern Illinois economy.
- 6,800 acres of mostly open land.
- Employs ~ 1,800 people and hundreds of subcontractors.
- Provides research facilities for ~ 2,500 particle physicists including students.
- Hosts thousands of visitors each year, who take advantage of educational, recreational and cultural opportunities.

Illinois Proposal for 200 BeV Accelerator 1965



Courtesy: Adrienne Kolb, Fermilab

200 GeV March 1, 1972

Wilson toasts the NAL staff

The Weston Site

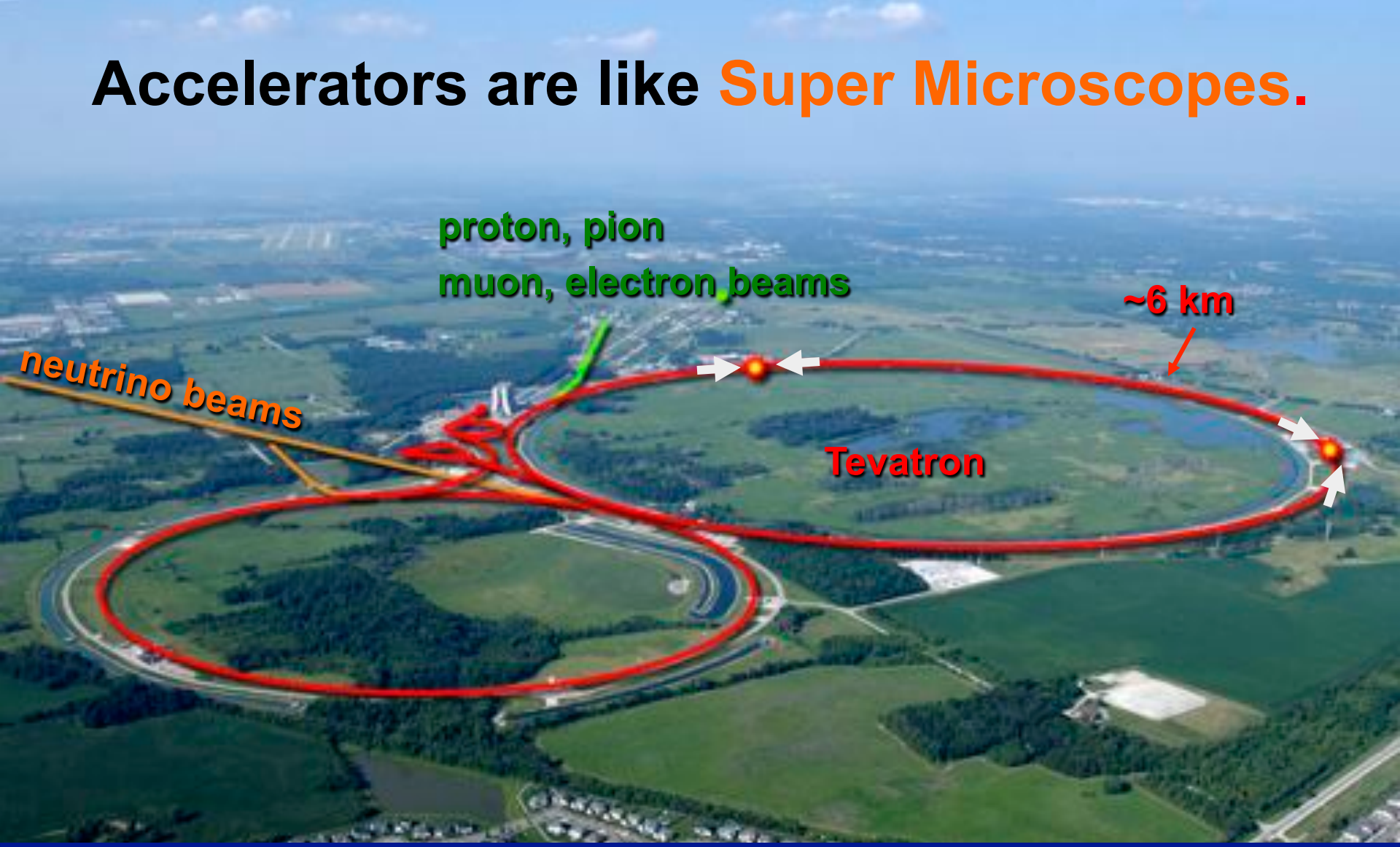
Courtesy: Adrienne Kolb, Fermilab

Fermilab, 1977

Before electronic data analysis, individuals visually examined photographs of Bubble Chamber particle interactions.

- Energy Doubler/Saver

Accelerators are like Super Microscopes.



Fermilab

World's 2nd Highest Energy Accelerator

World's Highest Intensity Neutrino Beams

How do we see particles?

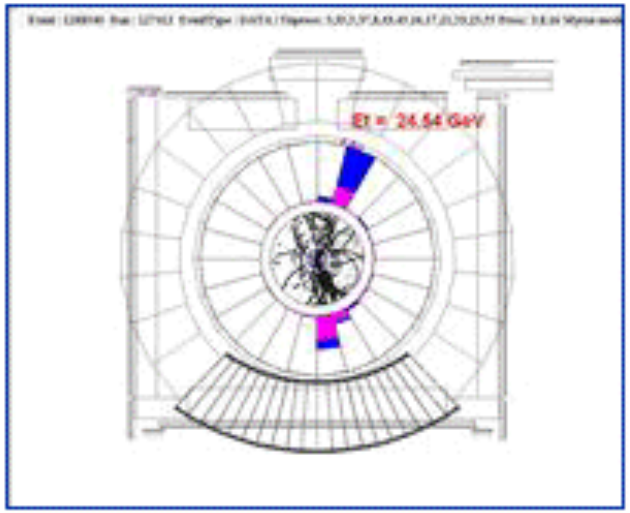
- To determine what happened in a collision we need to measure the directions of the produced particles, their charges and their energy.

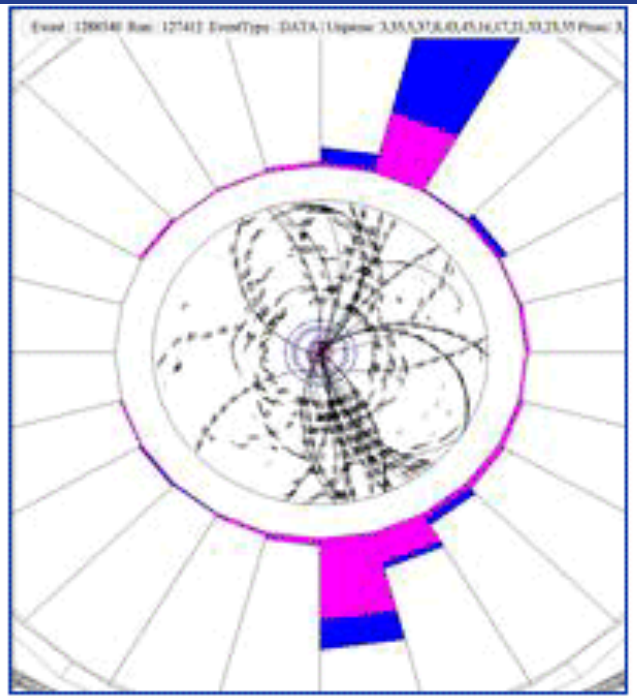
- Tracking devices reveal the trails electrically charged particles made by ionizing matter. In a magnetic field, the tracks curve, with the higher energy particles curving less than low energy particles

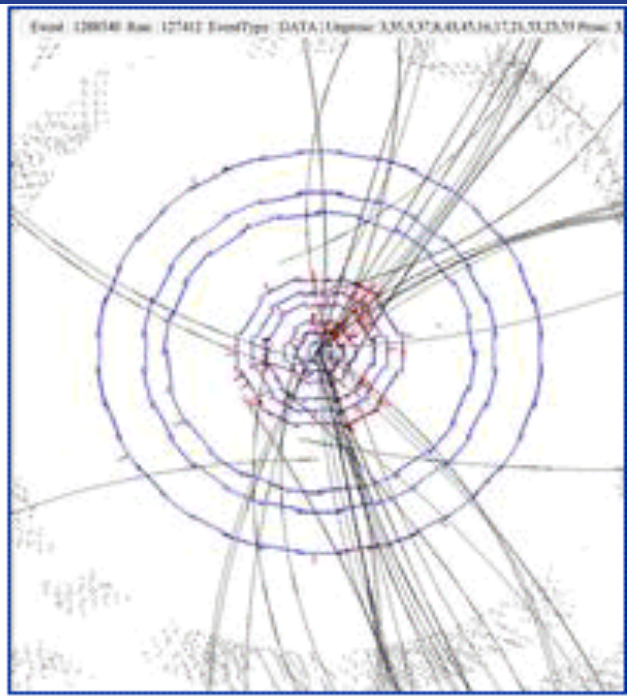
- Calorimeter are devices that measure the energy of particles by stopping them and measuring the amount of energy released.

An Event Picture

Dec 3, 2001







End view of the entire CDF detector

Close-up showing tracks + energy

Close-up showing tracks with hits in the silicon system

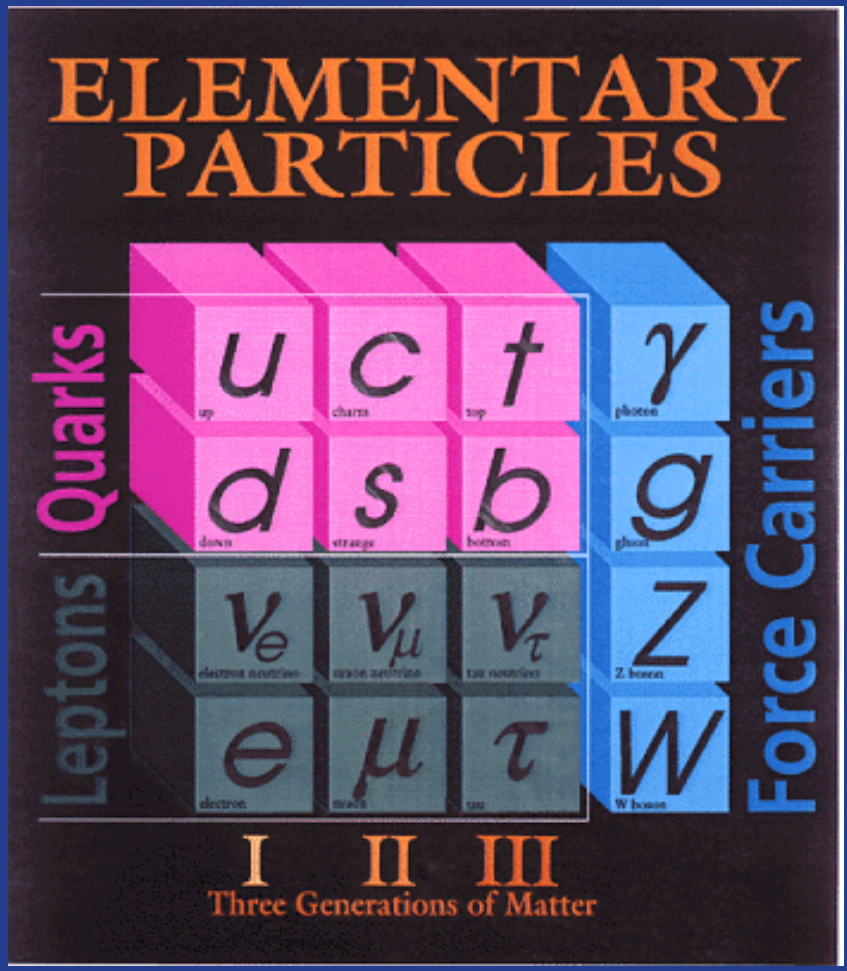
Courtesy: William Wester, CDF

Fermilab

Particles

- **Discoveries**
  - top quark 1995
  - bottom quark 1977
  - ν_t (tau neutrino) 2000
  - direct CP violation 1999
  - (with CERN)

- **Some critical measurements**
  - *t* and *W* mass 1998
  - QCD at highest energies 1988
  - proton structure 1984-95
  - charm lifetimes 1985-95



Open Questions in Particle Physics

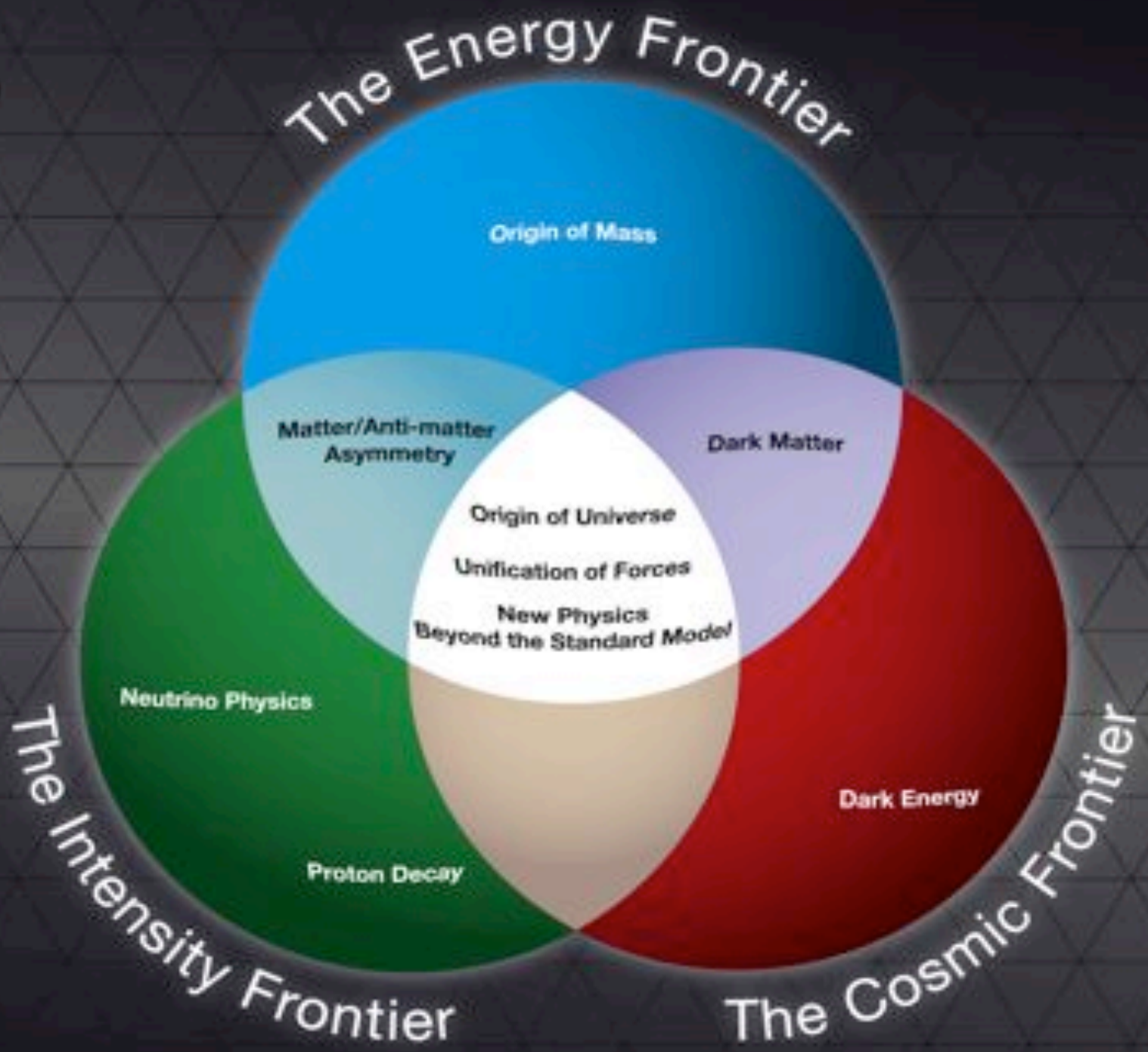
- What is the origin of the mass?
- What mysteries are generated by the Higgs?

- What is dark matter? What is dark energy?

- Why is there more matter than antimatter in the universe?

- Why are there many different kinds of elementary particles? Do quarks and leptons have substructure?

P5


The Energy Frontier
Origin of Mass
Matter/Anti-matter Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics Beyond the Standard Model
Neutrino Physics
Proton Decay
Dark Energy
The Intensity Frontier
The Cosmic Frontier

Future Lectures this Summer

André de Gouvêa: Intensity Frontier, June 18

Don Lincoln: Energy Frontier, June 25

Rocky Kolb: Cosmic Frontier, July 2

Harrison Prosper: Modern Physics, July 13

The Cosmic Frontier: Quarks to Cosmos

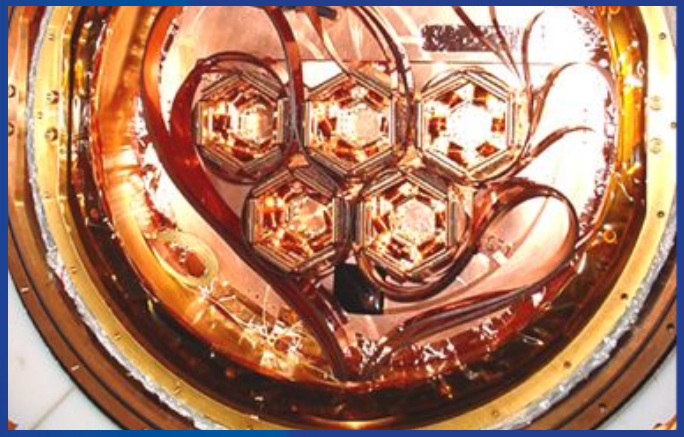
Dark Matter

Dark Energy

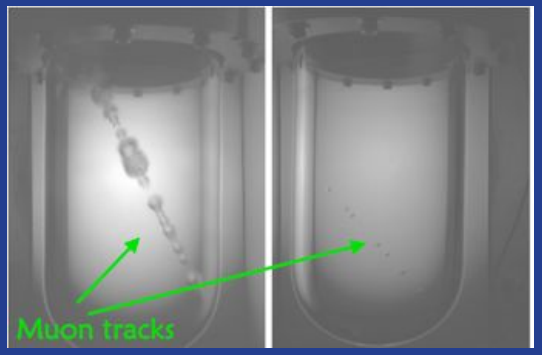
Ultra High Energy Cosmic Rays

Underground Dark Matter Detectors

CDMS
Low temperature crystals



4 kg → 15 kg



2 kg / 1 liter

COUPP
Room temperature bubble chamber

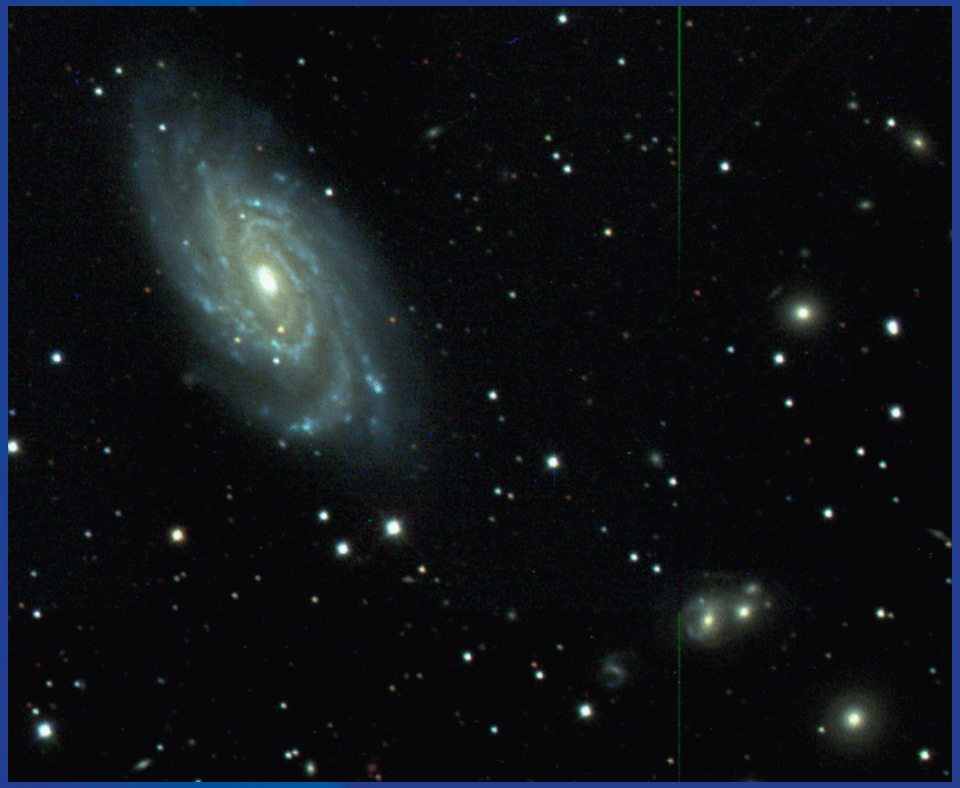
Probing Dark Energy

1. SDSS (Sloan Digital Sky Survey)
   - 2.5 meter telescope in New Mexico
   - Ranks as one of the facilities with the highest impact on astronomy .
   - Power spectrum of galaxies constrain dark energy density parameter.

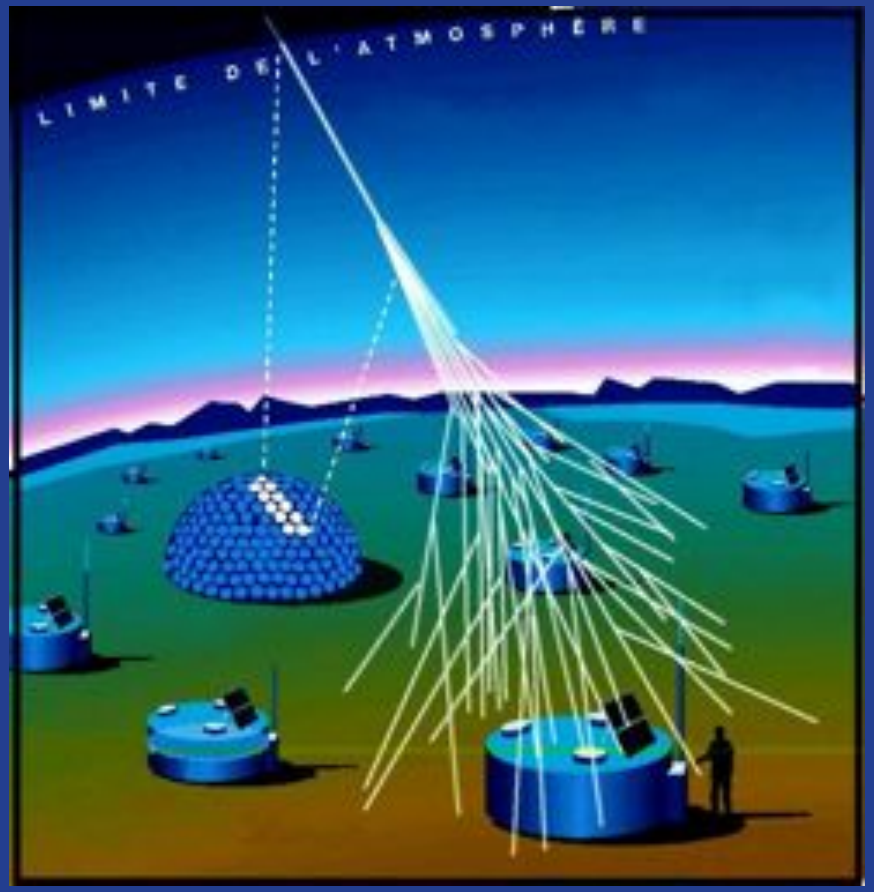
2. DES (Dark Energy Survey)
   - 4 meter telescope in Chile
   - DES Camera: Completed and installed
   - Operation: 2011 – 2016

3. JDEM (Joint Dark Energy Mission)
   - Space telescope
   - Fermilab Goal: Engage in the Operations and science

Outer Space Astrophysics

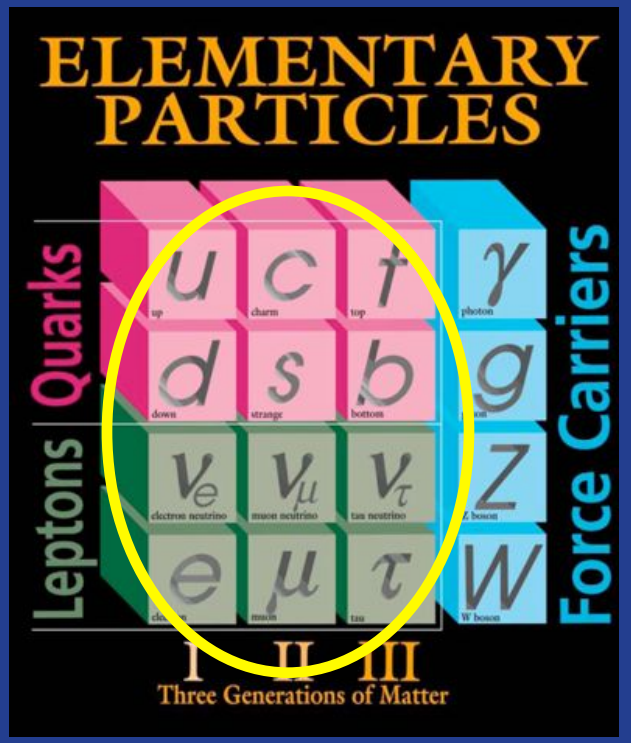


Sloan Digital Sky Survey



Pierre Auger Observatory

The Intensity Frontier

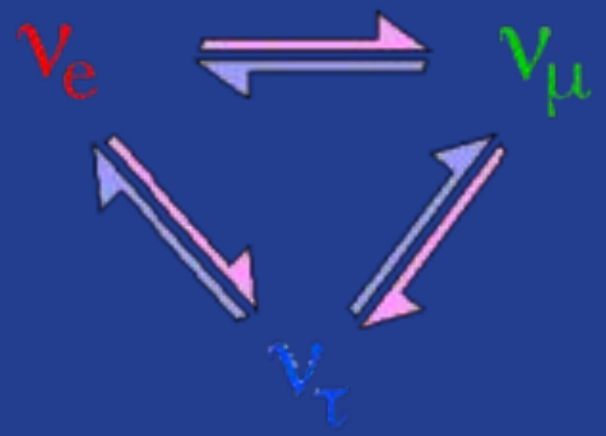


Physics of Flavor

- Flavor phenomena
  - Essential to shaping physics beyond the SM.
- SM is incomplete:
  - Neutrino Masses (flavor)
    - Exceptional new physics seen in the laboratory
  - Baryon Asymmetry of the Universe (flavor)
  - Dark Matter
  - Dark Energy

Intensity Frontier: neutrinos now

- **Neutrinos:**



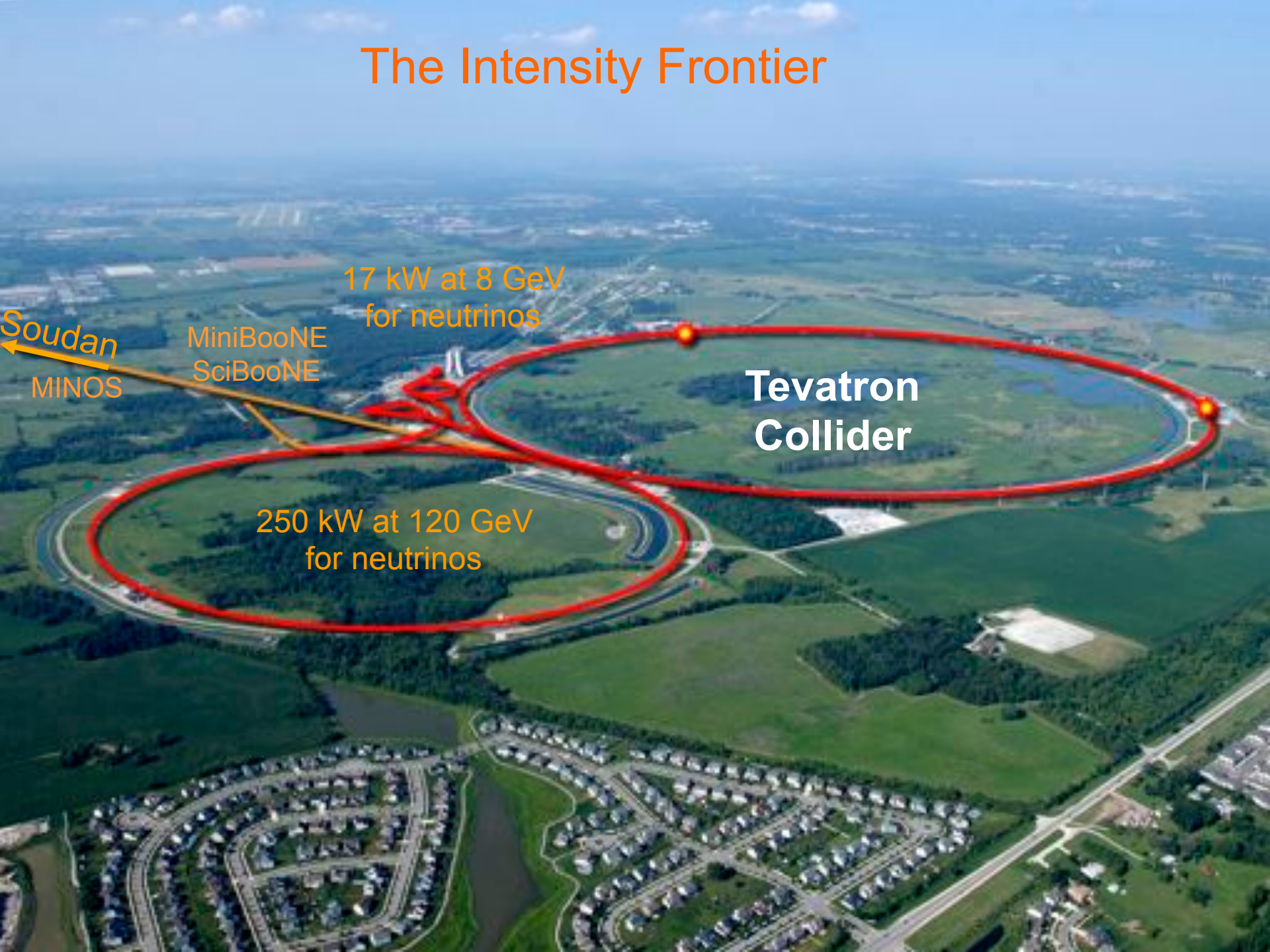
The enigmatic neutrinos are among the most abundant of the tiny particles that make up our universe.
To understand the universe, must understand neutrinos.

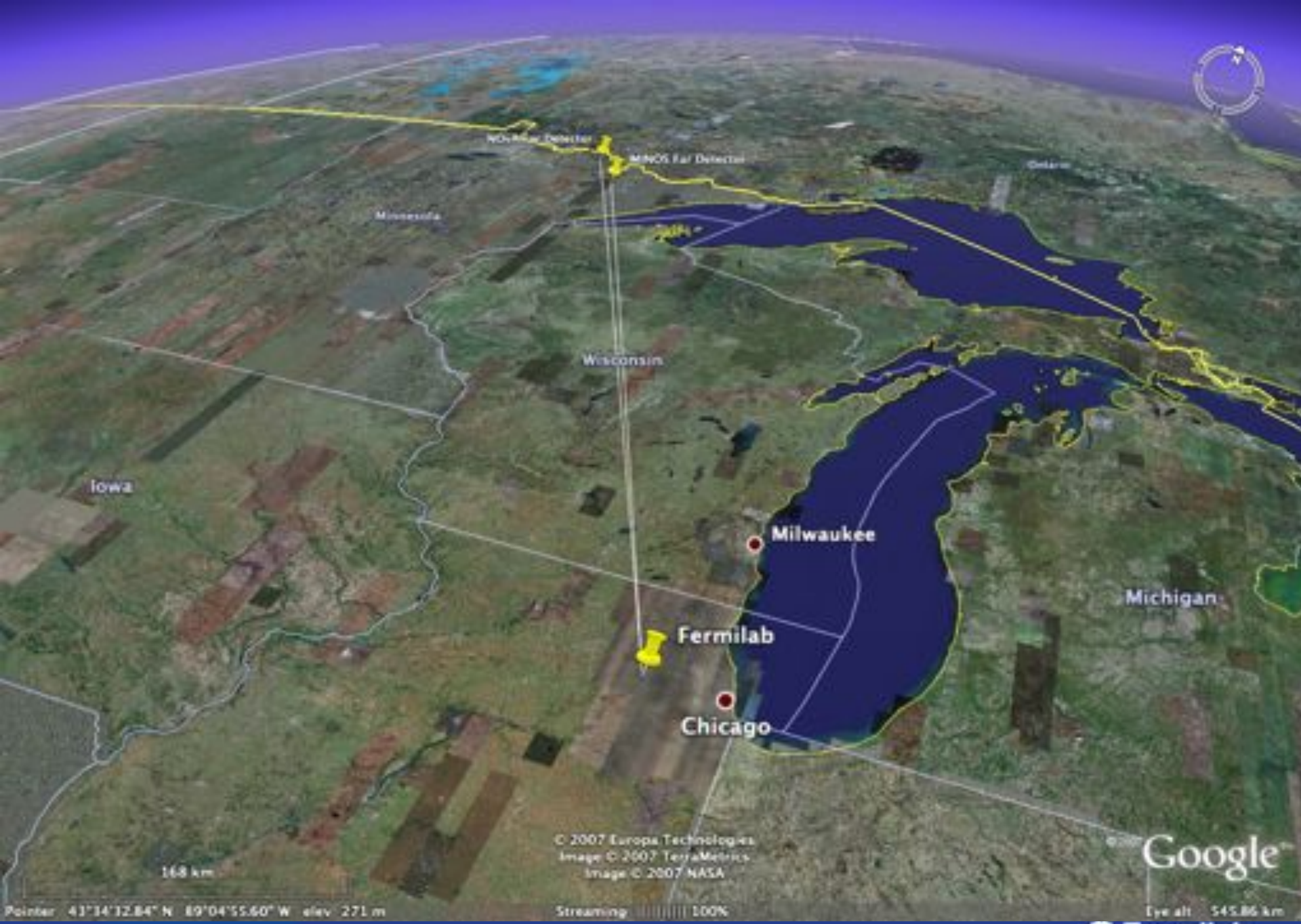
Behavior is so different from other particles.

Opening a "new" window

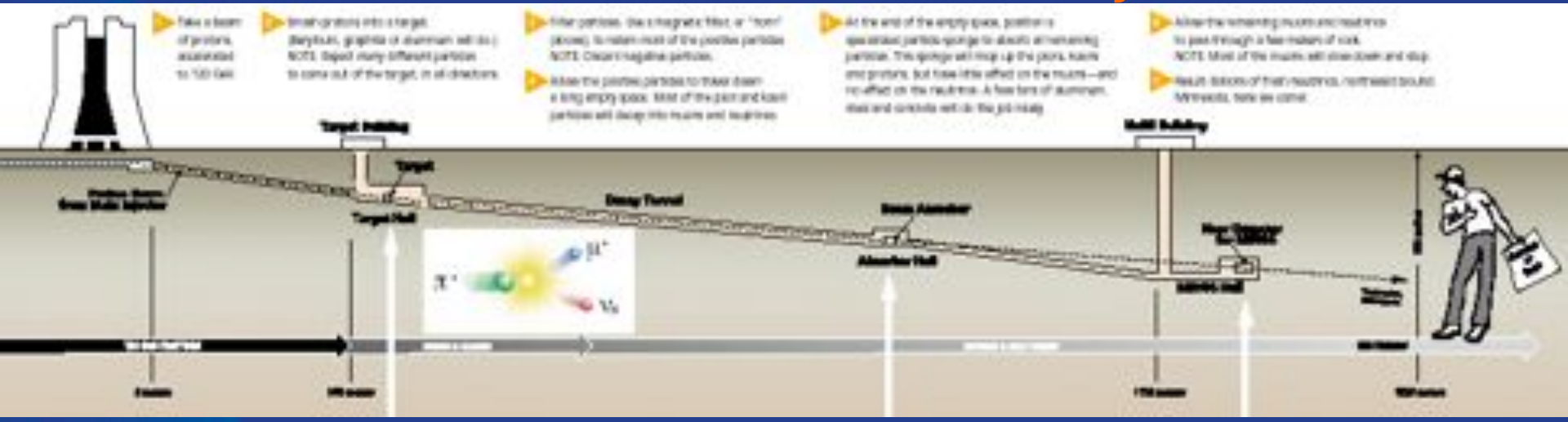
New and future info: θ_{13}, $\bar{\nu} = \nu$, mass ordering, CP violation

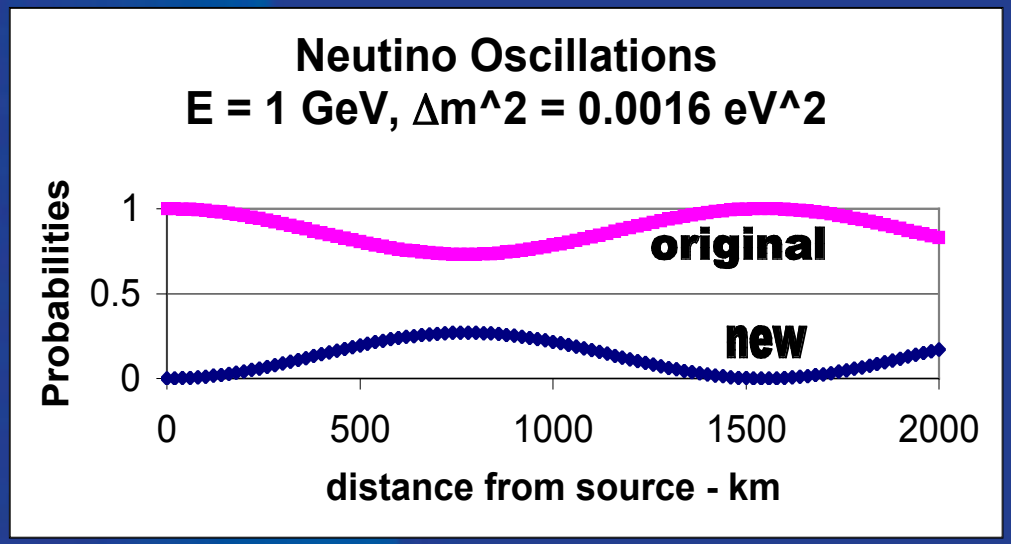
The Intensity Frontier

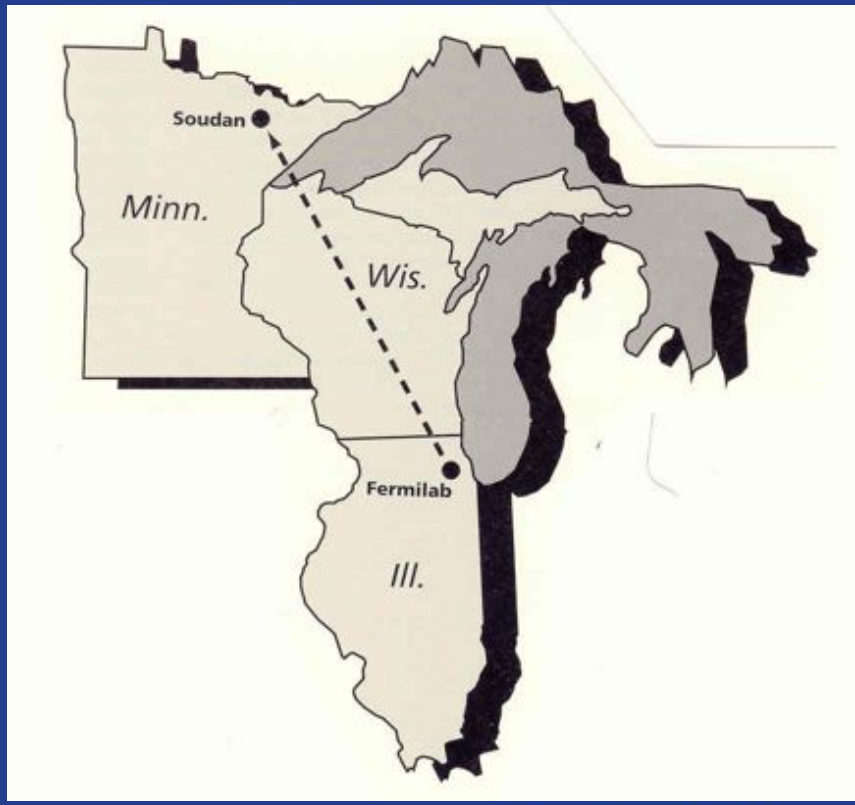



NOvA Far Detector
MINOS Far Detector
Minnesota
Wisconsin
Iowa
Milwaukee
Michigan
Fermilab
Chicago
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Image © 2007 NASA
Google
168 km
Pointer 41°34'32.84" N 89°04'55.60" W elev 271 m
Streaming 100%
Eye alt 545.86 km

NUMI – Neutrinos at the Main Injector



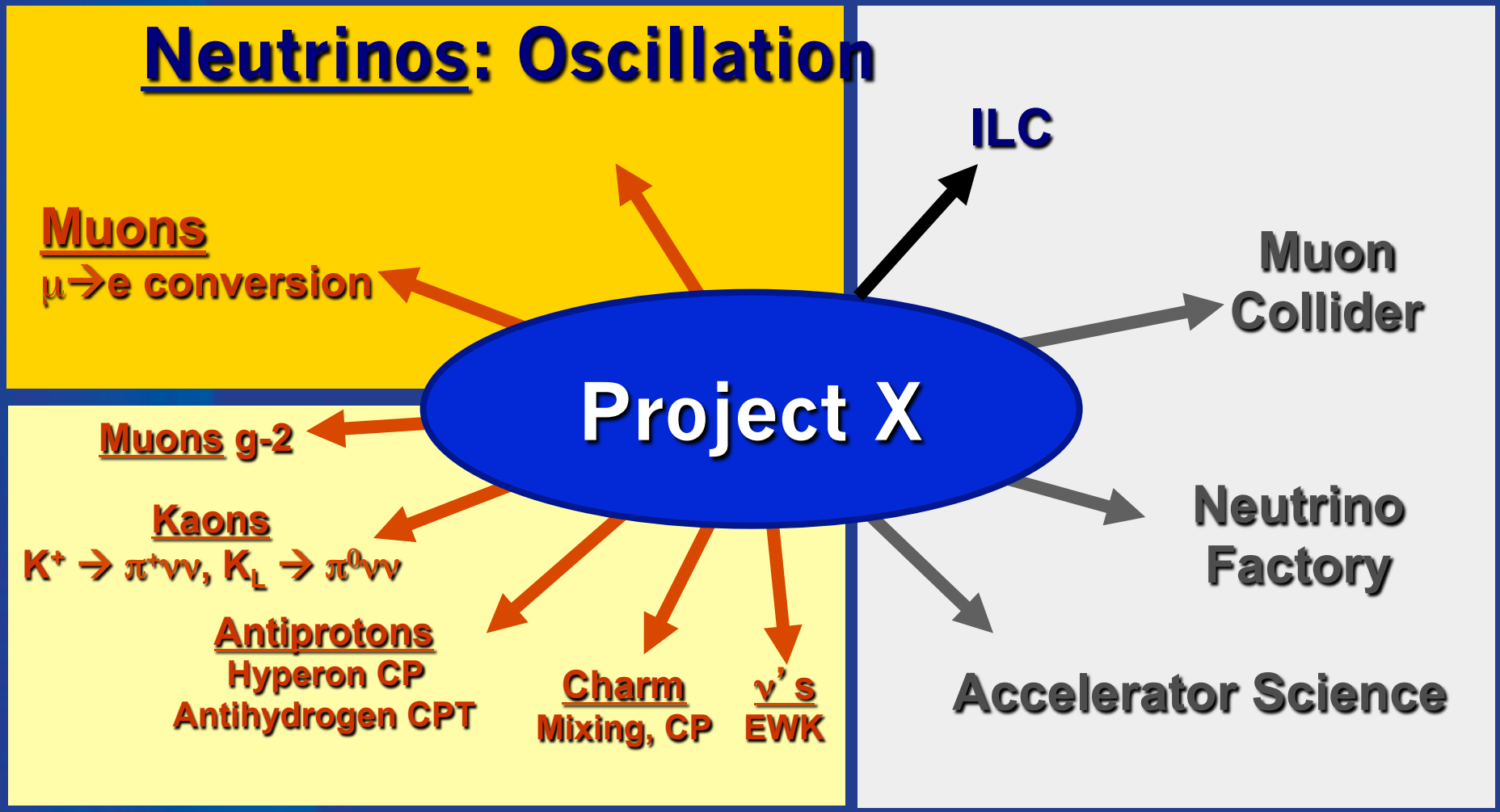




735 km long beam, right through the earth! 10 km deep

Future Planning for Fermilab

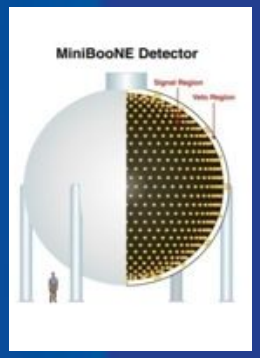
Opportunities with Project X

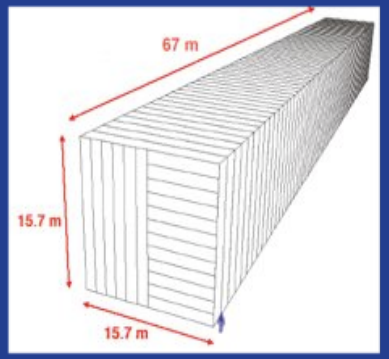


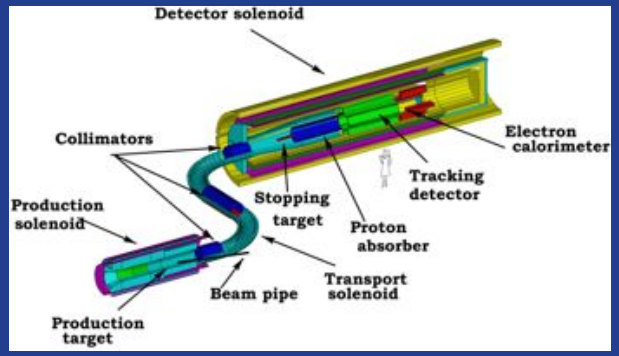
US HEP community and International Partners

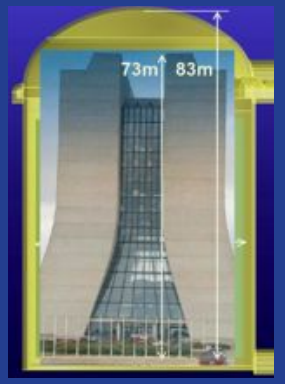
Project X

Present plan: intensity frontier

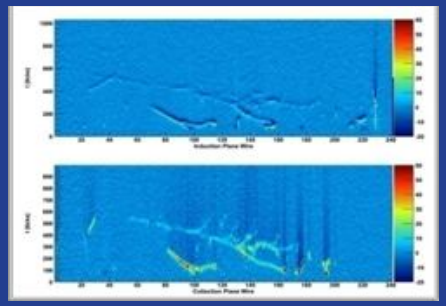


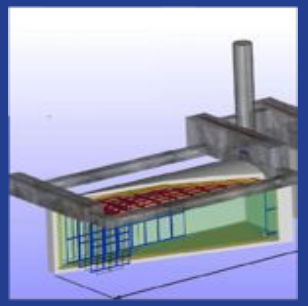






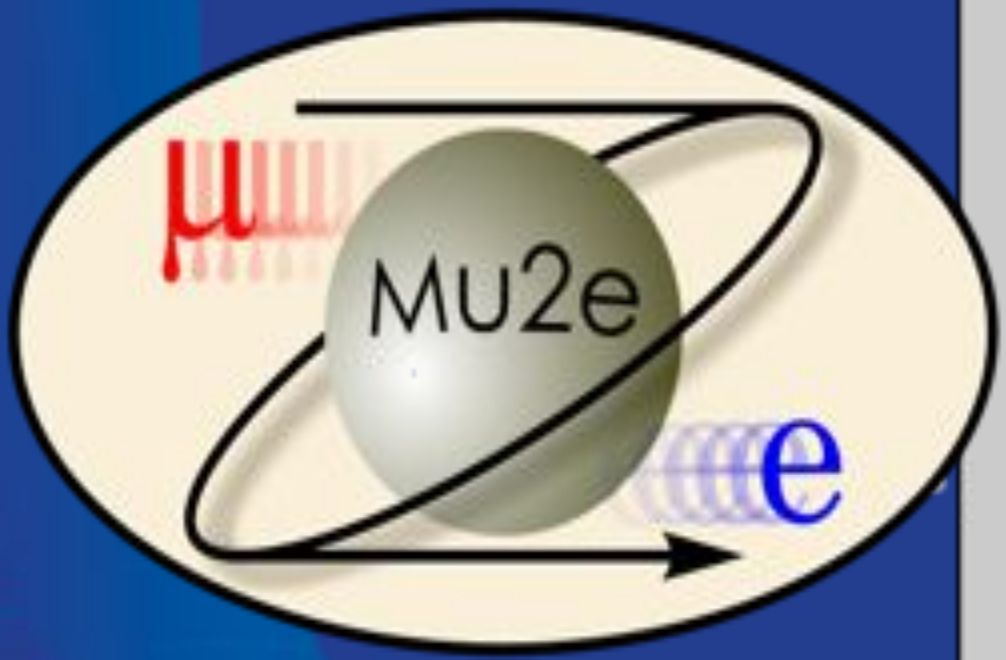
Now	2013	2016	2019	2022
MINOS MiniBooNE MINERvA SeaQuest	NOvA MicroBooNE g-2 SeaQuest	LBNE Mu2e	Project X+LBNE μ, K, nuclear, … ν Factory ??	

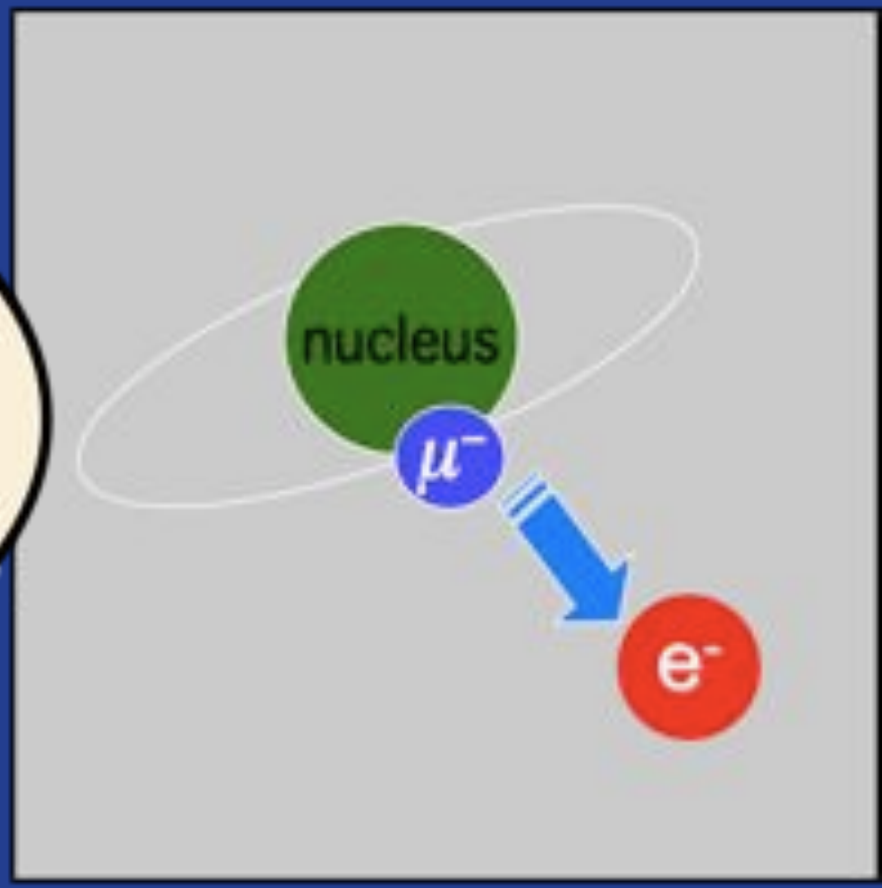




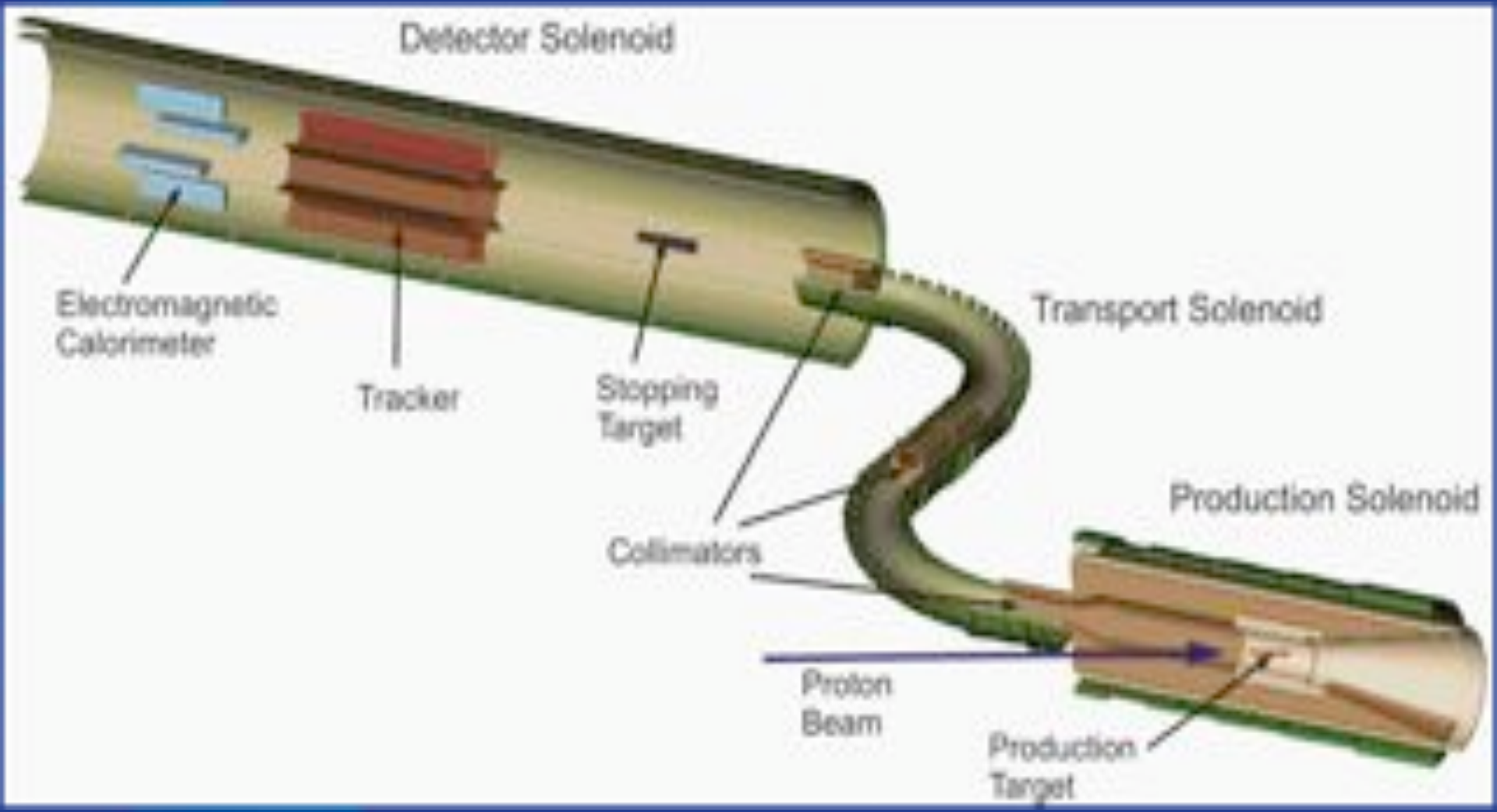
Muon to Electron Conversion

$$\mu^- N \rightarrow e^- N$$





Detector and Solenoid



Benefits of Fermilab Research

- **Increase our understanding of nature and how it works**

- **Technological spin-offs – much of today's economy is based on late 1800s – early 1900s research on the electron →**
  TV (accelerator) & communications

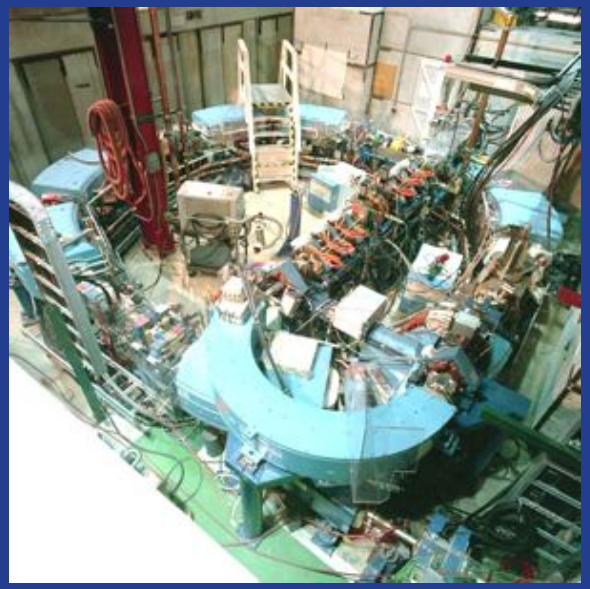
ENGINEERING

Maurice Ball: Mechanical Engineering

Dan Wolff: Electrical Engineering

- Civil, Electronic, Safety

Neutron Therapy Facility (Partner) – R. R. Wilson
Proton Accelerators for Medicine – Loma Linda & PET



SC wire – Tevatron → practical MRI

WWW – invented @ CERN by Tim Berners-Lee

Fermilab

SCRF Tech: Broadly Applicable at Fermilab

Great Engineering

DISCOVERY

- Extracting and understanding a phenomena for the first time!
- Leading to answers and often more questions
- Usually a piece of a puzzle that took some time to ascertain
- Often connecting many separate fields of study
- Enjoyment!

Lincoln University, 1946

Courtesy: Leo Baeck Institute, New York & The Albert Einstein Estate

Conclusions

We continue to smash the nuclei that make up our universe and everyday we learn something new!

I do hope that you will join us!!

Fermilab